

REPORT
OF
VISIT TO ENGLAND AND SCOTLAND

BY
FINN JONASSEN

NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL

Advisory to
SHIP STRUCTURE COMMITTEE

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Division of Engineering and Industrial Research
National Research Council
Washington, D. C.
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*Advisory
member of*

NATIONAL RESEARCH COUNCIL

2101 CONSTITUTION AVENUE, WASHINGTON 25, D. C.

COMMITTEE ON SHIP STEEL

OF THE

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

April 1950

Chief, Bureau of Ships
Code 440
Navy Department
Washington 25, D. C.

Attention: Captain C. M. Tooke, USN

Dear Sir:

I transmit herewith a report covering my trip to England and Scotland during November and December, 1949.

Through the splendid cooperation of the Office of the Naval Attache in London, the Admiralty, private research organizations and a number of universities, the trip was made most instructive and stimulating.

Sincerely yours,



Finn Jonassen
Technical Director
Committee on Ship Steel

FJ:mh

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A. STEEL

Meeting with Sir Amos Ayre, Chairman, The Shipbuilding Conference.

Discussed the entire research program as conducted both under the Board as well as under the Ship Structure Committee, especially the work pertaining to the quality of ship plate. Sir Amos is strongly of the opinion that the steel industry should aggressively pursue a research and development program so that it could produce a better steel. He feels further that such better steel should be sold at no extra cost. This belief is based on the usual procedure that research leads to better and generally cheaper products.

In discussing the quality of ship plate with Sir Charles Lillicrap, Director of Naval Construction, Admiralty, he is of the opinion that no matter how well a structure is designed and fabricated, minor flaws cannot be eliminated entirely and the only way to reduce the possibility of fracture is through the use of a better quality steel. He supports Sir Amos Ayre in the expectation that such better steel should be available as the result of the research program at no extra cost. They concur that when better shipbuilding steel is available, all-welded ships will give satisfactory performance.

In my discussions with Admiralty representatives at Rosyth and Bath, concern was expressed regarding the quality of ship plating steels presently available. They felt strongly that the quality of ship plate must be improved, in fact, they expressed the opinion that the steel should first be improved and then design and fabrication studies conducted using these better steels. Concern was expressed that wrong conclusions might be drawn if structural design research is based on inferior materials and welding techniques. Warren and Robertson seemed particularly interested in problems related to brittle fracture and are considering whether they can study the behavior of steels by attempting to evaluate the stress to propagate cleavage fracture. They seem very able

investigators, and of course appreciate the difficulty of separating the stress and energy necessary to propagate a brittle cleavage fracture, particularly since this phenomenon is probably more a function of local stress rather than of the nominal stress existing in the structure.

I discussed the preliminary sampling and study of ship plates from 8 different heats of steel from each of 6 different companies with representatives of the British Iron and Steel Research Association (BISRA). This effort represents the initiation of a program on the part of the British Steel industry to "know your steel". The heats will be rolled into the following thicknesses:

2 heats - 1/2" plate)	
2 " - 3/4" ")	
2 " - 1" ")	From each of six different steel
2 " - 1 1/4" ")	companies.

These steels will represent commercial production to Lloyds Register of Shipping's specification. This preliminary survey is expected to be completed in the Spring of 1950, and based on it a more comprehensive study will be planned. The preliminary study is being coordinated by BISRA through a new committee known as the "Notch Ductility Survey ad hoc Committee." This Committee will operate under the following terms of reference: to carry out a survey of notch ductility, over a range of temperature, of current production British ship plates, using economical and practical types of mechanical test. The new Committee is composed as follows:

Dr. C. Sykes, F.R.S. (Chairman)	Brown-Firth Research Laboratories
Mr. W. Barr	Colvilles Ltd.
Mr. G. M. Boyd	Lloyds Register of Shipping
Mr. A. J. K. Honeyman	Steel Company of Wales

Mr. T. F. Pearson	Consett Iron Co., Ltd.
Dr. L. Reeve	Appleby Frodingham Steel Co., Ltd.
Dr. S. Livingston Smith	British Shipbuilding Research Assn.
Mr. W. W. Stevenson	Dorman Long & Co., Ltd.
Mr. S. Wood	South Durham Steel & Iron Co., Ltd.

The samples are to be selected by the industry and will be tested both in the steel works laboratories as well as by Dr. Tipper at Cambridge University. The works laboratory studies will include one or more of the following tests while Cambridge University will probably use all.

1. Notch tensile test (Tipper test)
2. V-notch Charpy (Izod)
3. Slow bend test - it is being developed by Mr. W. Barr.

Sufficient steel will be put aside so that all tests can ultimately be made as desired.

In my discussion of the above, I suggested that the use of the keyhole impact test be included if they desired to tie this work in with the similar survey conducted in the United States by the AISI at the suggestion of the SSC. Copies of the AISI - SSC report should be sent to the above Committee as soon as possible.

I received a copy of a schedule of the research projects BISRA is supporting. Also a copy of the Progress Report on "The Brittle Fracture of Ferrous Materials" (Project MG/A/73) by N. J. Petch. This work was done at the Cavendish Laboratory under the direction of Dr. Orowan. Petch is now at Leeds University.

Work on the development of microspectrographic analysis has been done by A. J. Vaughn, formerly at the Bragg Laboratory. Vaughn is now Deputy to Barker of the RNSS.

The materials problem was discussed with representatives of Lloyds Register of Shipping - in particular, the question of criteria for performance, i.e., energy and appearance of fracture. Can these terms be used interchangeably? In addition, the following questions were raised: Do we want a steel which will break with a shear fracture? Do we want a steel which will absorb considerable energy and then break? Do we feel that the performance of the large scale tests (wide plates and hatch corners) are representative of ship performance? The above topics were discussed at considerable length without, however, any definite conclusions being drawn.

It is noted that Lloyds has revised its "Rules For Quality and Testing of Materials" requiring that plates having a thickness greater than $1/2$ ", the manganese content shall not be less than $2\frac{1}{2}$ times the carbon content, and more particularly, that "when the main structure of a ship is intended to be wholly or partially welded, the Committee (Lloyds) may require parts of primary structural importance over 1" in thickness to be of steel, the properties and processes of manufacture of which shall have been properly approved for this position." Both of the above changes are in line with the recently modified ABS specifications for ship steel and will generally provide for a more notch tough material. A copy of a portion of Lloyds rules showing this change is attached as EXHIBIT A. The demand for improving the quality of British steel is not widespread because no serious failures have as yet been experienced in British built welded ships.

In my discussions with representatives of British shipyards, they expressed confidence that the quality of British steel would keep them out of trouble and they relied completely on Lloyds to change material specifications for welded construction when such changes are considered necessary.

NOTICE No. 1919.



LLOYD'S REGISTER OF SHIPPING.

NOTICE IS HEREBY GIVEN THAT AT A SPECIAL MEETING OF THE GENERAL COMMITTEE, HELD ON THE 28TH JULY, 1949, ADDITIONS AND AMENDMENTS WERE MADE TO THE UNDERMENTIONED SECTIONS IN THE SOCIETY'S RULES FOR THE CONSTRUCTION AND CLASSIFICATION OF STEEL SHIPS AND STEEL TRAWLERS.

RULES FOR QUALITY AND TESTING OF MATERIALS.

Page 465, Section 1, Clause 8. The form of certificate has been amended to read as follows:—

"We hereby certify that the material described below has been made by the Open Hearth process, and in accordance with the Rules of Lloyd's Register and is that which has been satisfactorily tested in the presence of the Surveyor."

Clause 12 has been deleted and replaced as follows:—

12. **Alternative Proposals.**—The Committee will be prepared to consider proposals for the use of steel having properties different from those prescribed in these Rules, provided full particulars of the properties and manufacture of the material are submitted for consideration.

A new Clause 13 has been added as follows:—

13. **Special Requirements.**—When the main structure of a ship is intended to be wholly or partially welded, the Committee may require parts of primary structural importance over 1 inch in thickness to be of steel, the properties and process of manufacture of which have been specially approved for this purpose.

Page 467, Section 4. A new Clause 1 has been inserted as follows and existing Clauses 1 and 2 renumbered 2 and 3.

1. **Specification.**—(a) The steel shall not contain more than .06 per cent of sulphur or .06 per cent phosphorus.

(b) For plates having a thickness greater than $\frac{1}{2}$ inch the manganese content shall not be less than 2.5 times the carbon content.

(c) The chemical contents referred to in (a) and (b) above are to be determined from ladle analyses.

(d) For special requirements see Section 1, Clause 13. For Regulations for Testing of Special Quality Steel for Shipbuilding see Section 7.

A new paragraph (c) has been added to existing Clause 2 (now renumbered 3) as follows:—

(c) For Bend Tests for Shipbuilding Steel see Section 3.

Existing Clause 3 has been renumbered 4.

RULES FOR STEEL TRAWLERS.

(A new Edition is now in print.)

Page 57, Section 26.

A new sentence has been added to clause 1 (b) as follows :—

. . . and an efficient locking or brake arrangement is to be fitted to keep the rudder steady when a change of gear is required.

A new clause 3 has been inserted as follows and existing clauses 3 and 4 have been renumbered 4 and 5.

3. All trawlers exceeding 150 feet in length fitted with rod and chain steering gear are to be provided with a set of spare gear consisting of 1 buffer spring, 4 connecting links and 4 rod pins.

By order of the Committee,
P. E. CLEMENT,
Secretary.

71, FENCHURCH STREET, LONDON, E.C.3.
28th July, 1949.

As an outcome of an extended discussion with Dr. E. Orowan of the Cavendish Laboratory at Cambridge, the following over-all comments stand out:

1. A question of fundamental interest is why steel (or perhaps more generally, body centered cubic metals) have particular tendency for notch brittleness. On the present theory, which Dr. Orowan feels we have no reason at present to doubt, the occurrence of notch brittleness is determined by the relative magnitude of yield stress and brittle (negligible ductility) strength. We would understand why a certain metal is notch brittle only if its yield stress and brittle strength could be calculated very accurately. At present, such calculation is not possible and unless there is an unexpected easy access to the solution, he feels that work along these lines may not be a promising proposition. In this regard, study of the mechanism of fracture may give valuable clues.

2. All experience seems to indicate that the notch brittleness of ferritic steels is a constitutional, not an accidental, property. To remove it sufficiently by purely metallurgical methods such as alloy additions and changes in deoxidation practice, may not be economical. Dr. Orowan therefore proposes that consideration be given to the synthesis of plates of such texture (essentially laminated plate) that crack propagation requires a large amount of plastic work.

Dr. Orowan feels that concentration on the development of several experimental techniques will assist greatly in obtaining new and important information on the brittle fracture phenomenon. These are:

1. The development of a successful replica technique for steel for use in electron microscopy.

2. The development of a procedure for measuring the amount of plastic flow directly in the surface of the fracture.

Two projects involving studies of material at high rates of loading have been started in the Engineering Department at Cambridge University. One study, under Mr. J. Gibson, involves the testing of tension specimens wherein a loading frame is energized by a spring loaded sliding bar. The sliding bar is caught on its first recoil and in consequence, only one cycle loading is involved. The second study, under the leadership of Viscount Caldecote, involves the impact on a loading frame of a mass consisting of a free piston whereby specimens are subjected to high speed tension loading. The piston is slipped into a cylinder and energized by high pressure air. When the air pressure has reached the desired value the sliding piston and rod are released through a mechanical trip. Both of these high rates of loading studies are of interest to the Admiralty. They are in the development state but reports from the project under Gibson will be available fairly soon.

This is an outline of the work under way at National Physical Laboratory on a study of pure iron and binary ferrites.

In the early work of this investigation, the material produced was brittle. The fractures were inter-crystalline, but even so, manifested the transition temperature phenomenon. (Very approximately - the inter-crystalline fractures gave transition temperatures about 50°F higher than the pure iron produced later). The brittleness was eliminated by the use of a larger furnace but even with present practice, this type of brittleness may occur if grain size becomes large. The reasons for this brittleness are not known. In this earlier work, 5 to 7-pound heats were made.

At present 25 pound ingots of pure iron or iron alloy are being cast. Two such heats can be made per week. The ingot is octagonal - 2 3/4" across flats and is 11" long, and has a 2 1/2" x 3" diameter header.

The base material for these studies is Swedish iron which has initially the following analysis:

C	0.015	Cr	0.003
Si	0.015	Cu	0.006
Mn	0.008	O	0.044
S	0.006	N	0.01
P	0.001 or less	Al	Not detectable spectrographically
Ni	0.003 - 0.006		

The alloy content is now reduced by melting in an air furnace lined with magnesite (pure MgO is too expensive). The magnesite is free of sulphur and no impurities are picked up. The resulting analysis is:

C	0.006 - 0.008	Cr	0.001 or less
Si	0.002 - 0.004	Cu	same as before
Mn	0.004 - 0.007	Al	less than 0.001
S	0.004 - 0.005	O	0.2 - 0.4
P	less than 0.001	N	0.012
Ni	same as before		

The material is now melted under a hydrogen atmosphere resulting in the following analysis.

C	- 0.0026 - 0.008 (later melts 0.002 to 0.004)
Si	- 0.007 (later melts 0.001 to 0.003)
Mn	- 0.008 (later melts 0.004)
S	- 0.006 (later melts 0.001)
P	- 0.0015 or less
Ni	- 0.007
Cr	- 0.002 or less

Cu - 0.006 - 0.007

Al - 0.001

O - 0.0037 (other heats 0.001, 0.0008, 0.0007)

N - 0.0015 (vacuum fusion)

H - less than 0.000005

The furnace lining used when melting under the hydrogen atmosphere was pure sintered alumina. This liner was renewed after 4 or 5 melts. The above chemical analyses are based on material from the ingot headers.

Up to the time of my last visit, about 45 25-pound heats had been cast. Of these, 5 were pure iron, 10 were Fe-Mn up to 5% Mn, 6 were Fe-Si up to 5% Si, 2 were Fe-Mn-C with Mn equal to 2% and C equal to .03 and .05, 3 were Fe-C with C equal to .01, .03 and .05, 17 were Fe-Si-Cr.

The ingot is cropped and then forged, and then rolled into a rod producing 16-17 feet of 5/8" diameter rod from each ingot. The finishing temperature is controlled by starting the last pass at 1100°C - the last reduction is about 10%. The rod is cut into about 3' lengths and normalized at 950°C. The furnace is brought up to temperature and the bars are inserted - they remain in the furnace for about 15 minutes. The bars are hung in air about 1 foot apart to cool. The grain size following the normalizing treatment is 3.5 grains per millimeter for the pure iron (the grain size for the alloys had not been determined as yet).

V-notch impact bars and tensile bars are prepared. The impact bars are manufactured by the shop in the Engineering Division and are subjected to comparator check. Only a limited number of bars are used to determine the transition temperature (about 8 bars for each curve). The metals tested show an extremely steep transition front, often producing

slopes approaching infinity. Some values of the transition temperature are:

	<u>C</u>	<u>O</u>	<u>Si</u>	<u>Mn</u>	<u>Trans. Temp.</u>
Pure iron	0.0058	0.0008			-14°C
"	0.008	0.0018			-15°C
"	0.0026	0.0037			-16°C (coarse grain)
"	0.0025	0.016			-18°C
"	0.005	0.0017	0.013		- 5°C
Fe-Mn	0.0046	0.0026		0.03	-19°C
"	0.0035	0.0016		0.20	-28°C
"	-	-		1%	-26°C
"	-	-		2%	- 7°C
"	-	-		2%	-50°C
"	-	-		3%	-24°C
"	-	-		3%	-20°C
"	-	-		5%	-102°C
"	-	-		5%	-112°C

It is noted from the above table that ranges of composition for pure iron (with the exception of the heat in which the oxygen content had become excessive) may produce as much as 30°C difference in the transition temperature. Major emphasis is being placed on producing successive melts of the same analysis to study the spread in the values of transition temperature.

At the time of my last visit further work was being held off because of questions regarding control in the rolling operation. By mistake, one of the 2% Mn heats was rolled to 1/2" diameter instead of 5/8" diameter. This change, following the normalizing treatment, produced a harder material by 22 points as measured using the Vickers indenter.

It is anticipated that a report covering the early phases of this work will be available during the summer of 1950.

The investigators have inquired as to whether related activity in the United States would require Swedish iron. In order to obtain this material, it appears desirable that organizations requiring Swedish iron for their work should pool their requests so that a larger amount may be prepared at the same time. Requests should be forwarded to Tigerschiold of Jernkontort in Sweden.

The research program under the cognizance of the Committee on Ship Steel was discussed with Prof. D. Hanson, Dr. A. H. Cottrell, and Dr. G. V. Raynor of the Metallurgical Department, University of Birmingham. They indicated particular interest in the new project at Carnegie Institute of Technology (SR-108) and the companion project on binary ferrites being investigated at the University of Pennsylvania (SR-109). Current work under the guidance of Dr. Cottrell includes mechanical tests on single crystals and polycrystalline materials. Some of his work is reported in a recent paper entitled "Dislocation Theory of Yielding and Strain Aging of Iron" by Cottrell and Bilby, Proceedings, Physical Society, A., Vol. LXII, page 49. In addition, Cottrell had submitted a discussion on a recent paper by Holden and Hollomon entitled "Homogeneous Yielding of Carburized and Nitrided Single Iron Crystals" in the Journal of Metals, November 1949. This discussion describes further work at Birmingham. Another paper is entitled "Effect of Sulphur on Brittleness Due to Overheating" by Hanson and Cottrell, J.I.S.I., Jan. 1950. Because of their interest in the work of Project SR-108 and 109, and several others, I promised to arrange a direct interchange of technical reports.

In discussing the research program with Mr. Hignett of the Mond Nickel Company, he also indicated interest in Projects SR-108 and 109, and 111.

He also showed interest in the work on the effect of plate thickness. In consequence, arrangements have been made to transmit copies of reports of the Swarthmore College work. In discussing the research program on the preparation of pure iron in both Great Britain and the United States, as well as the preparation of the "homogeneous" heat of steel, Mr. Hignett was emphatic in calling attention to the possible deleterious effects of tramp elements. He felt strongly that the raw materials must be watched closely. The research work at the Mond Nickel Company has shown that Arsenic, Antimony, Tin, and Bismuth are undesirable elements in alloy steel as determined by the impact notch bar test. Mr. Hignett indicated that there was some chance that Carbonyl iron may be available at a future date, made immediately following a plant shut down and cleaning particularly to remove nickel. Mr. Hignett is interested in the work of the SSC and would like to receive a copy of the Board Report. In commenting on the extensive specimen development program. Mr. Hignett recommended that consideration be given to the use of notched impact bars of differing widths whenever this was possible.

Following a discussion with members of the Admiralty Shipwelding Committee, they felt it would be entirely in order if reports of certain SSC investigations were transmitted directly to British investigators, such as Cottrell and Hignett.

Following an extended discussion with members of the staff of Messrs. Colvilles, Ltd., particularly Mr. W. Barr, the following items appeared significant:

1. They feel strongly that the Mn/C ratio is effective in reducing the transition temperature. Further, they feel that the transition temperature is reduced by virtue of an increase in Mn content. A research program is currently being pursued to study this matter. That is, to

determine whether it is the ratio that is effective, or whether it is the increase in Mn or possibly the decrease in C that depresses the transition temperature. This study is being conducted on 18-lb induction furnace melts. (Whatever conclusions are reached, based on these small melts will have to be demonstrated using full scale production heats.)

2. The occurrence of occasional superior heats of semi-killed steel was discussed. What elements in the steel making practice (besides finishing temperature and grain size) governed this? Perhaps when these elements are known, controls can be instituted whereby a homogeneous product of constantly lower transition temperature can be achieved. Certainly, since occasional superior heats are made, it should be possible to consistently duplicate such better semi-killed heats. Further study may show that such better semi-killed heats are sufficiently notch tough to insure the safety of welded ships. These comments may be particularly significant when it is recalled that in the U.S.A. as well as in Great Britain, in the event of another "emergency", fully killed notch tough steels will not be available for shipbuilding. Furthermore, in such an event, even the use of high manganese may have to be restricted and consequently semi-killed ship steel could only be supplied in normal Carbon (.20/.25) and Manganese (.40/.50).

3. It is known that appreciable differences occur in the notch sensitivity of commercial steels. These differences are not intended - indeed it was desired that the steels be alike. Reasons for these observed differences may lie in variations in grain size, finishing temperature, and many others. Steels being currently produced in several of the mills of Messrs. Colvilles, Ltd., are currently being studied with reference to their transition temperatures. Since the observed differences are large, it is felt that any one of the presently available notch bar test specimens

will be sufficiently discriminatory. Accordingly, in this study the V-notch impact test is being used. Further investigations to inquire into the effects of strain rate, prior strain history, etc. may require refinement in the type of notch specimen.

Messrs. Colvilles, Ltd. is developing a fully killed "grain controlled" steel for use in welded ships. This steel will contain about 1% Mn and it is planned to supply plates in the normalized condition. These steels will be known as the "Coltuf" series and should give 30 ft. lbs. or more at -10°C . A report covering some test results for these steels is available. 2,000 tons of this type of steel has recently been supplied Kockums Mekaniske Verkskeds A/B for their use in the midship area of two welded tankers. (This steel was supplied to the Swedish buyers at an extra over base of about \$40.00 [L10]). The plates varied in thickness from .65 to 1.64 and were normalized singly at $880 - 900^{\circ}\text{C}$. A report on some of these steels is available.

Although arrangements had been made for an interview with Dr. N. F. Mott at the University of Bristol, he had to cancel this appointment at the last moment. I did have a chance to discuss some aspects of the work at Bristol with several of the graduate students, particularly Mr. D. J. Millard, who very kindly made available to me a progress report on the work he is doing on a study of single crystals of Cadmium. Copies of this report have already been sent to Dr. Mehl at Carnegie Institute of Technology and Dr. Marzke at the Naval Research Laboratory.

I discussed the research program of the Ship Structure Committee, particularly those projects under the cognizance of the Committee on Ship Steel, with members of the Physics Department faculty at Bristol. As an outcome, it is recommended that technical progress reports of investigations SR-108, 109 and 111 be forwarded directly to Prof. N. F. Mott, Wills Physical Laboratory, Royal Fort, Bristol 8.

I discussed the metallurgical aspects of the Ship Structure Committee's program with Prof. J. H. Andrew at the University of Sheffield. Professor Andrew appeared most interested in the research work that is just being initiated and would be very pleased to place some of his facilities at our disposal through work that might be done by graduate students. He is particularly desirous of doing work involving the determination of the effects of hydrogen on steel.

I also discussed the SSC's program with Prof. H. W. Swift who is especially interested in problems involving deep drawing and lubrication. The shops and research facilities at the University of Sheffield are excellent and they should therefore be in a position to make real contributions. It is recommended that because of the enthusiastic interest on the part of both Prof. Andrew and Prof. Swift that these contacts should be maintained and their assistance sought.

The following papers were called to my attention at various times during my visit because of their probable interest to members of the SSC or investigators on SSC projects.

1. "Mechanical Properties of Low Carbon, Low Alloy Steels Containing Boron," W. E. Baraggett and Reeves, The Engineer, Nov. 25, 1940, p. 617.

(This is a review. The article actually appears in the Journal of the Iron and Steel Institute.

2. "Plastic Behavior of Solids", by Sir Andrew McCance, The Engineer, Nov. 4 and 11, 1949. (This paper will also appear in the Journal of the Iron and Steel Institute).

3. "Engineering Steels under Combined Cyclic and Static Stresses," by Gough, The Engineer, Nov. 4, etc. 1949.

4. "An Investigation on Bandings," Journal of the Iron and Steel Institute, by J. D. Lavender and F. W. Jones, September 1949.

5. "The Influence of Oxygen, Nitrogen and Carbon on the Impact Strength of Iron and Steel," by J. D. Fast, Preprint #7, International Foundry Congress 1949, Amsterdam. (Published in: Metalen Congresnummer 1949).

At its third meeting the Committee on Ship Steel or the National Research Council recommended that a study of the inherent scatter characteristics of the V-notch impact test be initiated. It was proposed that the study be made on a "homogeneous" steel which would be produced in fairly large quantity by the best commercial procedure. Because of differences of opinion existing in the CSS, this project and the order for the homogeneous steel have not been initiated. The desirability of conducting such a study was discussed with a number of investigators in England, including Dr. Crowan, Mr. Hignett and Mr. Barker and associates (RNSS). Without exception they felt that the study would be most useful in giving us a limiting condition of scatter based on the V-notch impact test as determined from a high grade commercial heat. Mr. Hignett recommended strongly that the raw materials going into such a heat be watched carefully, suggesting that consideration be given to starting with Swedish iron.

(Some information in the direction proposed above has already been gotten from the work at NRL in which approximately 30 laboratory heats intended to be alike have been tested using the V-notch impact bar. These results indicate the reproducibility of identical lab. heats to have transition temperatures within $\pm 15^{\circ}\text{F.}$)

Just before leaving I was able to spend some time with Dr. C. F. Tipper, thereby enabling us to cross reference comments on her American visit and on my British visit. Some salient points drawn from her American visit are as follows:

1. Concern over the large number of notch test specimens which are currently in use in the United States. The picture is

indeed confusing when it is realized that about the only tests in use in Great Britain are (a) the V-notch impact test and (b) the Tipper tension test.

2. Dr. Tipper feels that emphasis needs to be placed on a study of the "scale" or "size" effect.
3. Because of the large number of small scale tests in use in the United States, Dr. Tipper felt that attempts should be made to determine the relationship between these tests, thereby hopefully assisting in justifying a reduction in the number of types of specimens in use.

B. STRUCTURAL TESTING

The British Shipbuilding Research Association is supporting a number of projects involving the over-all strength of ships as well as investigations involving a study of the detail design of hull components. These studies are conducted under such headings as:

1. Determination of load stresses and deflections in ships' structures.

Work under this heading is closely allied with that of the Admiralty Shipwelding Committee whose program of full-scale tests on the OCEAN VULCAN are in the process of being completed.

A "Bibliography on Strength of Ships" has been compiled by H. Torrence and issued as Report #23, September 1948. (In reading this report it is noted that unfortunately, the latest Transaction of SNA&ME considered for this bibliography was that of 1944 and consequently the paper on the PHILIP SCHUYLER was not included. It is also noted that the paper entitled "Torsion of Ships" by G. Vedeler, Institution of Naval Architects, 1924, has not been included. Additional value would be given to this bibliography if the unpublished reports of the U. S. Maritime Commission on the static structural tests of a number of Great Lakes ore carriers and tankers could be included. These are listed as reference 4, 6, 8, 9 and 10 in the Board Report.) A copy of this report is available. Structural models of various sizes and containing varying amounts of stiffness are being studied by Prof. A. J. Pippard in the Department of Civil Engineering, Imperial College, University of London. A number of progress reports covering this work are available in mimeographed form. A Technical paper covering some of this work was read by Prof. Pippard at a Structural Symposium

held at the University of Bristol in the summer of 1949. The papers presented at this Symposium are to be published in book form as the Colston Research Papers, Vol. II. Copy of this volume is on order. (The progress reports mentioned above have already been made available to Mr. John Vasta of the Bureau of Ships and are on hand to be forwarded to others interested.)

2. Stress concentration studies. As an outcome of this type of investigation, it is expected that a better distribution of material can be obtained. Some information under this heading was obtained in connection with the tests on the OCEAN VULCAN. It is planned to obtain additional information in connection with the tests on components of ship structures to be discussed later.
3. Effect of Distance from Ship's side of Long Deck-house on Stresses Taken by the Latter. This study is being undertaken through an investigation of stress distribution in box girders comparable to the ship's hull. Preliminary reports on this work have already been submitted by Prof. Pippard, Imperial College. Progress reports covering some aspects of this work are available.
4. Expansion Joints. This study is also to be conducted as a model investigation. Rubber models will be used and the work is to be conducted by Prof. Pippard, Imperial College.
5. Tests of Components of Ship's Structures. The aim of this study is to provide useful design information by comparing riveted and welded construction of typical ship components. This project was started at Glengarnock by Mr. J. L. Adam of the British Corporation Register of Shipping. Several papers covering aspects of this work have been published. The synopsis of two of the papers are

given below. A photograph of the old test set-up is shown as attached plate 1, Figure 1.

- a. "SHIP STRUCTURAL MEMBERS", by J. L. Adam, Member of the Council, Transactions of the Institution of Naval Architects, 1940.

Summary: The paper gives (1) the results of tests on compound girders formed of channel sections riveted to plating and having riveted bracket end-connections as commonly fitted in ships, (2) the effects of welding and end-connections and of various types of end-connections on such girders. (3) the results of tests on compound girders formed of welded sections on plating with various types of end-connection. (4) the effects of varying the rigidity of the base structure. (5) the amount of plating which contributes to the strength of girders."

- b. "SHIP STRUCTURAL MEMBERS" - PART III, by C. S. Lillicrap, C.B., Director of Naval Construction (Member), and C.J. G. Jensen, B., Sc., 20th April, 1945.

"Synopsis: - The paper gives the results of tests on (i) compound girders formed on 12" welded sections on plating with varying face area and thickness of plating; (ii) 12" angle sections cut from 12" channels and web welded to plating; (iii) compound girders formed of 10" special sections, including 10" flat bar, welded to plating; (iv) compound girders formed of 6" channel; 6" inverted angle (cut from 6" channel); and 6" bulb plate (cut from 6" bulb angle) on plating. The amount of plating which contributes to the strength of the girder and the effects of varying the rigidity of base structure are also given."

PLATE I



FIG. 1

A new testing machine has been designed and is being built at Glengarnock to permit a 24-foot span, a 300 ton lateral load and a 600 ton end load in tension or compression.

A study of the buckling characteristics of rectangular ship plate panels is being organized under Prof. J. F. Baker at Cambridge University. These test plates (approximately 2 feet square test section) can be subjected to uniform stresses normal to the plate surface (hydrostatic force) and varying degrees of biaxial stresses in the plane of the plate, in either tension or compression. The plates will actually be considerably larger, approximately 4 foot square, than the net test section. This will permit adjustments of slope across the supports so that the effect of various degrees of fixity can be obtained at the supports. The testing frame, etc., has been completed and the testing program should start shortly. The investigation is being conducted by Mr. B. Swindells. Photographs of the test arrangement are shown in Figure 2.

6. Application of Light Alloys. The aim of this study is to determine the properties and suitable applications of light alloy metals suitable for shipbuilding. A report covering aspects of this work, entitled "Aluminum Alloys and their Application to Shipbuilding" has been prepared by W. Muckle of Kings College, Newcastle. This is listed as Report #22, November 1948, of the BSRA. Copy of this report is available.

Herewith are some of the activities under way at the British Welding Research Association's testing station, Abington Hall, Cambridge:

1. Pressure Vessel Research:

- (a) The effect of cylindrical nozzles of various wall thickness is being studied on a 4'6" diameter by 10' long pressure vessel having a 1 5/8" wall thickness. The nozzles are 12" in

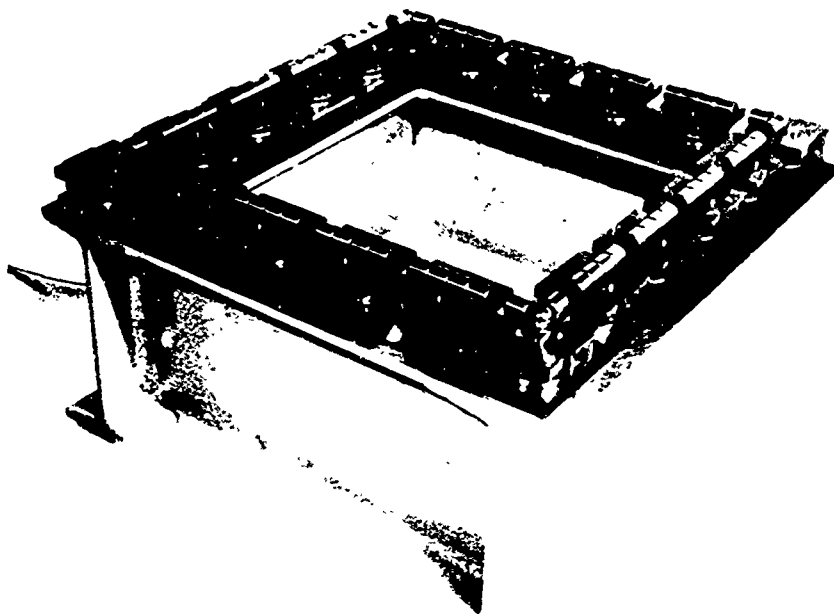
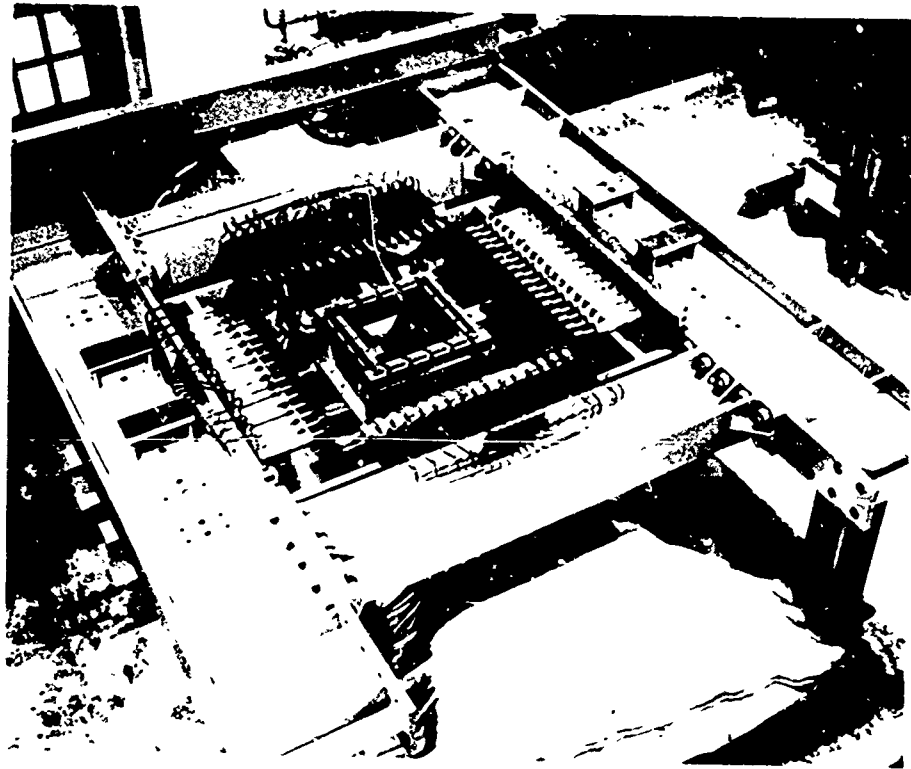


Figure 2

diameter and have wall thicknesses of $5/8"$, $1"$, $1\ 5/8"$. The nozzles are finished carefully into the contour of the pressure vessel. The pressure vessel is covered with SR-4 strain gages in the nozzle area - pressure vessel to be subjected to internal pressure (about 1,000 psi) at room temperature.

- (b) Other tests of tubes and elbows are being conducted - these specimens subjected to internal pressure as well as bending.
- (c) A triplex pump is used to obtain pressure up to 10,000 psi.
- (d) Fatigue test is being planned for subjecting pressure vessels to pulsating pressures.
- (e) Mr. Nicol Gross is in charge of this work.
- (f) Strain gage development work in this laboratory to be presented to the Experimental Stress Analysis Group, Institute of Physics and to be published in the Journal of Scientific Instruments.
- (g) A description of the waterproofing method used for the SR-4 strain gage was published in "Engineering", June 10, 1949 by Tannahill.

2. Fatigue Testing - (Resonance Flexure Fatigue).

- (a) The problem being studied is how to splice joints in deck frames or bulkhead stiffeners. The frames and stiffeners in the test specimens have been joined using various riveted and welded connections. The deck or bulkhead sections are wide enough to contain two frames or stiffeners.
- (b) Variations in the method of fastening the frame or stiffeners to the plate are also being studied. These include riveted and welded connections. The welded connections have such variations as continuous and discontinuous beads, scalloped frames, etc.

3. Structural Proof Testing (for Prof. Baker) of Full Scantling Portal Frames. Testing is done by applying dead weights. Basis of structure and performance have been worked out theoretically using Professor Baker's plastic theory and also by small scale tests. A number of papers and reports have been written on this important study. A recent one is "A Review of Recent Investigations into the Plastic Behavior of Steel Frames in the Plastic Range" by Prof. J. F. Baker, Institute of Civil Engineers, Paper #5702, 1948-49.
4. Following an extended discussion with Professor A. G. Pugsley of the University of Bristol, a number of references were obtained covering the development of the method of testing involving the test frame which is so extensively used in Great Britain. The work being conducted by Prof. Pippard involves this type of loading frame and the extensive program at the Aeronautical Laboratory, Farnboro also uses this method for testing aircraft structures. Several references describing such equipment are listed herewith:

"Stability of an Aircraft Structure in a Strength Test Frame,"

P. B. Walker, Journal Royal Aeronautical Society, Aug. 1947,
#440, Vol. 51.

"A Structural Test Frame with Automatic Loading, F. W. Page and
J. C. King, JRAS, October 1949.

"Principles of Aircraft Strength Testing," P. B. Walker,
Structural Engineering, Vol. XXVI, #11, November 1948.

Professor Pugsley informed me that serious consideration is being given to permitting materials to be used in aircraft structures having a 5% minimum elongation. This amount of ductility will be

permitted for the level of design obtaining in the average aircraft factory. For every carefully designed member, a material having a 3% ductility is being considered.

5. In my discussion with Sir Amos Ayre, he favored the testing to destruction of equivalent riveted and welded structures such as hatch corner specimens or even ships to produce fractures under states of stress that obtain under actual ship conditions.

C. REDUCTION AND ANALYSIS OF TESTS ON S.S. VULCAN.

I visited the office which Mr. Frank H. Bull has in his home where several clerks are engaged in performing computations on the OCEAN VULCAN tests. The following information was noted as the PROBABLE maximum stress values developed during the time sea observations were being taken. It is entirely possible that subsequent analysis may yield higher values. The maximum vertical and horizontal bending moment stresses stated below did not occur simultaneously but it is possible that they could.

- I. Max. stresses due to vertical bending moment. Deck, 3.4 tons per sq. in. tension. Bottom 2.8 tons per sq. in. compression.
- II. Stresses due to vertical bending moment 7 seconds prior to those in I above. Deck 3.2 tons per sq. in. compression. Bottom 2.5 tons per sq. in. tension.
- III. Stresses due to vertical bending moment 8 seconds after I above. Deck 2.6 tons per sq. in. compression. Bottom 2.3 tons per sq. in. tension.
- IV. The maximum horizontal bending moment was $\frac{f}{\text{30,000}}$ tons feet and the corresponding stress $\frac{f}{\text{1}}$ ton per sq. in.
- V. The above stresses have been based on the following:
 - (a) Horizontal $I/c = 31,200 \text{ ft. in.}^2$
 - (b) Vertical $I = 484,000 \text{ ft.}^2 \text{ in.}^2$
 $c_{\text{top}} = 17.3 \text{ ft.}$
 $c_{\text{bot}} = 20.1 \text{ ft.}$
- VI. For the conditions cited previously the still water bending moment stress was 3 tons per sq. in. tension in the deck. Thus the maximum deck stress so far possible based on the OCEAN VULCAN

study is 7.4 Tons/sq.in. This was determined as shown in the attached sketch, Figure 3.

An outcome of all the full scale ship tests, some experimental information is now available on -

I. Based on the Static Tests.

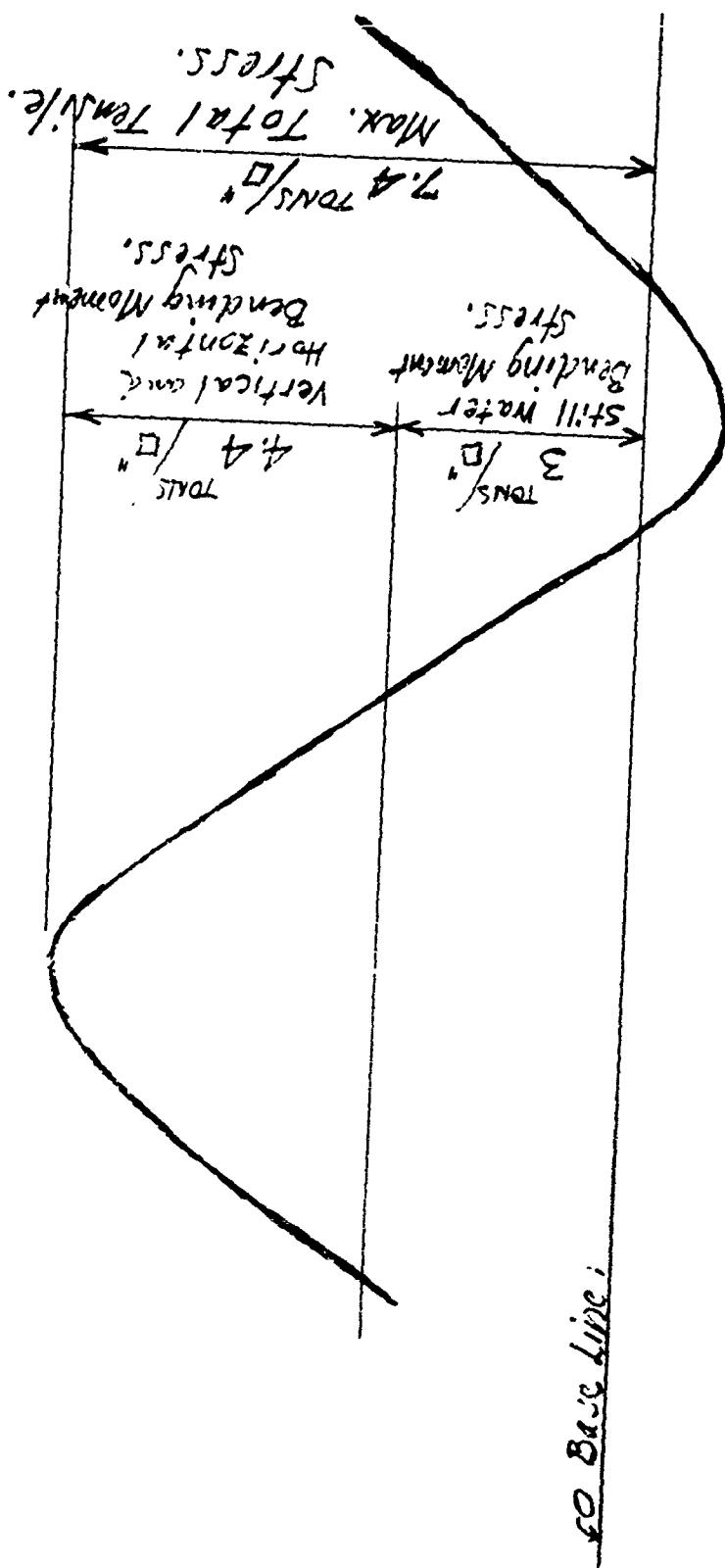
- (a) Tendency towards longitudinal buckling through (1) stress distribution in critical areas, (2) over all deflections.
- (b) Differences in behavior of various details (e.g. hatch openings) in riveted and welded ships. The general (over all) stress distribution in riveted and welded ships, aside from local conditions, has demonstrated once again that the stress is a linear function of the distance from the neutral axis.

II. Dynamic Tests.

- (a) The horizontal bending moment to which a ship may be subjected. It is shown that the stresses resulting from the horizontal bending moment may be as high as 30% of the stresses resulting from the vertical bending moment.
- (b) The torsional forces to which a ship may be subjected. It is shown that the stresses resulting from torsional moments are of no consequence.
- (c) A study is now being conducted (analysis) to determine the number of times the sea stress exceeds, say 3 tons per sq. in. Preliminary work indicates that the number of times is relatively small, perhaps one thousand times in 18 months. This is to be checked further from the records of the

4-10-50

- 30 -



Maximum Tensile Stresses so far
 Determined from the analysis of Ocean Vulcan Data.
 The peak stresses resulting from the Vert. and Horiz.
 Bending Moments did not occur simultaneously - but
 it is considered possible that they could.

FIG. 3.

OCEAN VULCAN as well as from the strain gage (statistical) now installed on the CAPE NELSON (ex OCEAN VULCAN). All the above data relative to the OCEAN VULCAN are currently being prepared as a paper to be presented probably before the Institution of Naval Architects.

D. SHIPYARDS

I. John Brown - Clydebank. This yard appears to have standardized on mixed riveted and welded construction - shell seams are riveted, butts are welded. The yard personnel indicated that they expect to continue the use of riveting at least to the extent mentioned. The yard has, of course, complete facilities for riveting and in many cases finds riveting cheaper than welding. If a shortage of riveters should develop, it is felt that they can attract apprentices into the activity and train them.

Bulkheads are welded and welded to the side shell. Longitudinal bulkheads are continuous. Brackets from interrupted longitudinals (tankers) are framed through the transverse bulkheads.

Plate edges are planed when prepared for welding.

This yard evidenced no concern over the quality of shipbuilding materials. They have had no serious problems arise which were traced to the notch sensitivity of ship plate.

II. Harland-Wolff, Govan. This yard indicated that for the present at least they would insist on the inclusion of several riveted fore and aft seams.

In smaller tankers they use straight bulkheads with vertical stiffeners. In the large tankers they will use corrugated bulkheads.

Fore and aft members are continuous, flame cutting is used for cutting plates to size and for edge preparation for welding.

No particular concern over materials. They have had no serious difficulties that were traced to the notch sensitivity of ship plate.

III. Vickers-Armstrongs, Walker - Newcastle upon Tyne. This yard is laid out so that it can swing from riveted to welded construction at will. Ships under way are being fabricated by riveting and welding.

All rivet holes in shell plating are drilled. The plates are usually stacked for the drilling operation. Only holes in some brackets and frames are punched. In welding certain sub-assemblies on the assembly platen, an automatic process of welding called "Fusarc" is used. The electrode for this method is coated and in the coating is contained a spiral wiring through which power is transmitted to the filler metal. Fusarc welding is used because the yard feels that poorer fit-up can be tolerated. In this method of welding, the operator can see the weld when it is being made but he, of course, needs glasses.

Portable X-ray equipment is used for spotting sub-surface defects. The yard has found this spot checking to have marked upward effect on the quality of workmanship.

Corrugated bulkheads are being installed in several of the tankers under way. In the longitudinal bulkheads the corrugations run fore and aft, while in the transverse bulkheads the corrugations are vertical. This orientation permits simple connections at the bulkhead intersections. In the transverse bulkheads, the sections near the bottom are of course heavier than those at the top.

- IV. Swan Hunter and Wigham Richardson - Wallsend. This yard, principally through the impetus of Mr. Norman N. Hunter, has done a great deal towards pushing the extensive use of welding as far as British shipyards are concerned. In fact, Mr. Hunter is so enthusiastic about welding that several 25,000 ton tankers are currently being built in which the only riveting is that joining the side shell to the frames. These tankers have longitudinally framed bottom shell and deck and a transversely framed side shell. The only reason the side shell is

riveted to the frames is because the yard finds that easier to do since it has no room for preparing large sub-assemblies and its crane facilities are limited. In the construction of all-welded ships, Mr. Hunter has, of course, complete confidence in British shipbuilding steel. In addition, the following factors are also considered:

- (a) Weight of steel in the top and bottom flanges of the hull girder.
Mr. Hunter feels that some welded ships being built are somewhat light in these areas. He illustrates this point by citing a ship for which the steel was estimated to weigh 7,000 tons by recommending that an additional 600 tons be added, distributed principally in the top and bottom flanges of the hull girder.
- (b) That a continuous watch is made for the elimination of notches, both in design and during fabrication and erection.
- (c) The welding workmanship is constantly watched. The yard requires that there be one overseer for every 15 welders and that each pass be inspected before the subsequent pass can be laid down.
- (d) That rigorous prescribed welding sequences be maintained.

If the above requirements are met, this company can and is building all-welded ships which they are convinced will be entirely successful. This yard finds that progressively fewer riveters are becoming available. Whereas in the past there were usually many gangs of apprentice riveters, at the time of my visit only one such gang was in operation at the yard.

V. Burntisland Shipbuilding Company, Burntisland. This is the yard which has been developed by Sir Amos Ayre and his brother, Sir Wilfred Ayre. This is a relatively small yard building both riveted and welded ships. It

has developed the use of riveted sub-assemblies, thereby making substantial cuts in production costs. The riveted sub-assemblies were hydraulically riveted and ships have been constructed in which one-third or more of the rivets were driven hydraulically. The yard is gradually swinging over to welding.

E. RESIDUAL STRESSES.

Some of the problems involving residual stresses were discussed with a number of investigators, particularly from the viewpoint of the preparation of the proposed Monograph on Residual Stresses. The discussion was based principally on the outline attached as Exhibit B, copies of which were left with each person interviewed. The following evidenced real interest in this undertaking and would like to participate in the preparation of a Monograph by contributing one or more papers under the sections of the Monograph in which they are particularly interested. Those with whom this problem was discussed included:

Prof. J. F. Baker)	
		Cambridge University
Dr. E. Orowan)	
Prof. Hanson)	
		University of Birmingham
Prof. Cottrell)	
Prof. Swift,		University of Sheffield
Dr. Taylor,		BWRA
Dr. Weck,		BWRA

Dr. Weck is, of course, deeply interested in the possible effects of residual stresses and I am certain he will be a most helpful contributor to the Monograph.

While the general viewpoint that residual stresses are not important factors in the ship fracture problem is accepted by most everyone in Great Britain there are still a number who are not quite convinced. Among these is Sir Chas. Lillcrap, DNC, who still feels that residual stresses may be important. He refers to himself as an "heretic" on the subject and feels that the case for residual stresses is still "not proven".

EXHIBIT B.

RESIDUAL STRESSES

- I. This is a suggested procedure for further study of residual stresses (internal stresses) with particular emphasis on determining the possible effect of such stresses on the initiation and propagation of brittle fracture through welded structures such as have occurred in ships.
- II. It is proposed to conduct this study by requesting experts on various aspects of the problem to write papers summarizing the state of knowledge of the subject. Such papers would of course be fully documented and a bibliography would be included.

These experts would be chosen from the scientific and engineering rosters of the U.S.A. as well as from foreign countries.

The authors would be requested to recommend experimental work they feel would be of value in order to fortify the conclusions drawn or to extend our knowledge of the subject.

It is anticipated that these authors would prepare the papers without cost and that the collection of such papers would form an integrated attack on the problem and would ultimately be published commercially as a monograph on the subject of residual stresses.

- III. To plan and coordinate this work, it is proposed that a Committee be appointed. This Committee would decide the subject of the papers (chapters of the monograph) and propose authors.

The Committee would also act as an editorial board and assist the authors by performing needed editorial functions.

In addition, it is planned that the Committee would prepare a brief synopsis of each chapter.

When the papers have been collected, it is planned that the Committee write a summary of all the chapters. This summary would then represent, in condensed form, a statement of our knowledge of the subject, based on information and opinions as expressed by some of the world's foremost scientists and engineers.

- IV. Some of the subjects which would be included in the monograph, together with a few names which might be considered by the Committee in selecting authors are:

A. Definition of the problem.

To be formulated by the Committee with the advice of the Ship Structure Committee.

B. Definition of residual or internal stress - macro and micro stress systems.

To be formulated by the Committee.

C. Origin of residual stresses.

1. Localized plastic flow.
2. Temperature gradients.
3. Localized volume change.

Suggested authors -	Baldwin	Norton
	Cohen	Orowan
	Gensamer	Sachs

D. Measurement of residual stresses.

Suggested authors -	Ffield	Rosenthal
	Norton	Soete
	Pascoe	Thomas
	Riparbelli	

E. Reaction of residual stresses and working stresses.

Suggested authors -	Baker	Orowan
	Brown Univ. Group	Spraragen
	MacGregor	Weck

F. Effect of residual stresses on initiation of fracture.

Suggested authors -	Cottrell	Orowan
	Hollomon	Taylor
	Mott	Zener

G. Effect of residual stresses on the propagation of fracture.

Suggested author - C. A. Adams

H. Latent energy in structure containing residual stresses.

Suggested author - Soderberg

1. Examples of fracture in which residual stress was thought to have played a role.

In discussing possible additional contributors to the Monograph with Prof. Hanson and Prof. Cottrell, they suggested the following:

Petch - Leeds University

Nabarro - University of Birmingham

Sykes - Brown-Firth Research Laboratories

N. P. Allen - NPL

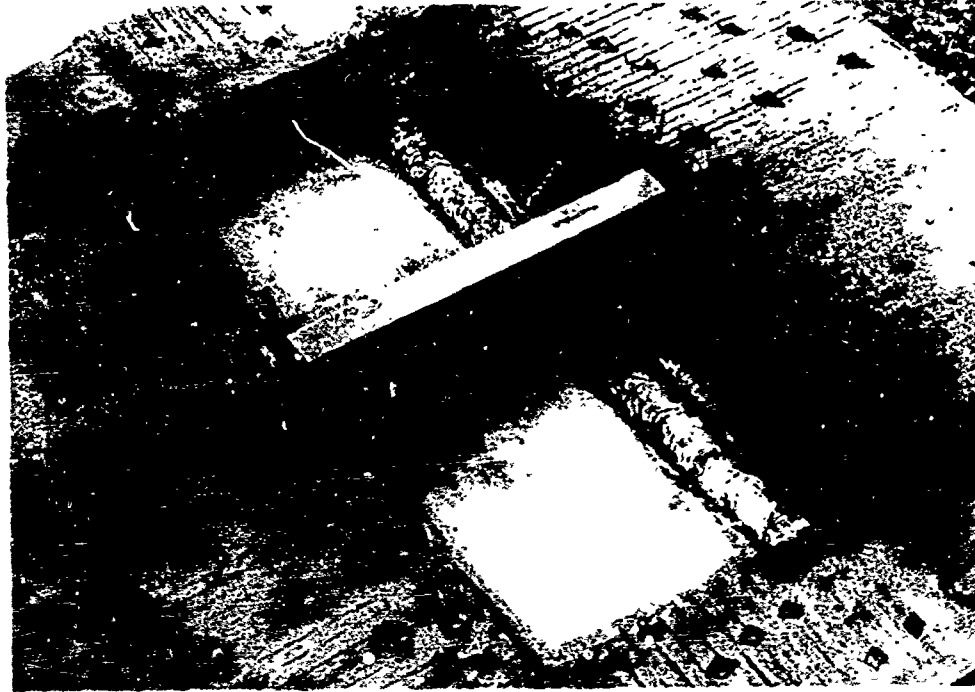
Dr. Weck, who also is Chairman of the Commission on Residual Stresses under the International Institute of Welding, called my attention to a number of recent articles on this subject:

1. "Classification and Nomenclature of Internal Stresses" by E. Orowan
2. "The Present Position on Residual Stresses in Welded Structures" by R. Weck.
3. "The Stress-Relieving of Welded Structures" by R. Weck, Welding, Vol. XVII, No. 10, October 1949.
4. "Residual Stresses in Metals", by Wm. M. Baldwin, Jr., Edgar Marburg Lecture, 1949.

Currently, a study is under way under the direction of Dr. Weck at Stewart and Lloyds at Kettering in which the effect of residual stresses is being studied as they influence the onset of fracture. This investigation is still in its very preliminary stages and involves welding a test specimen inside of a very heavy restraining frame. The specimen contains a notch perpendicular to the principal direction of loading. See Figure 6. The loading is obtained upon making the closing weld. This weld is also perpendicular to the principal direction of loading. Following the completion of the final weld, the test specimen is stressed in tension. The temperature of the whole assembly, including the frame, is now lowered to determine if a crack will propagate from the notch under a constant level of stress. It is assumed, of course, that the coefficient of contraction for both the steel frame and the specimen is the same.

The first specimen was fabricated and subjected to progressively lower temperatures down to -58°F . and no cracks resulted. It was then thought that the whole system might not be rigid enough and a restraining rib was installed on each side of the specimen, welding the rib to the specimen and to the restraining frame but not having any of the weld touch the transverse closing weld or the notch. Three additional specimens have been fabricated using the rib. In specimens #2 and 4 a steel designated as "A" was used. One specimen cracked at -10°C , (14°F) the other at -7°C (19.4°F). Specimen #3 fabricated of a steel designated as "B", showed no cracks at -60°C (-76°F). Based on the notch bar impact test, steel "A" was more notch sensitive than steel "B". The very first specimen which did not crack at -58°C , (-72.4°F) was made from steel "A", Drawings and photographs are attached as Figures 4, 5 and 6.

WELDING JIB PLATE MATERIAL IN HEAVY RESTRAINING FRAME.



*Specimen
3.*

Steel B.

Great Jib plate (0.212% carbon, 0.54% chromium, 0.288% molybdenum fine-grained steel) welded with preheat of 190°C. No indications of cracking were found after several hours at -60°C. At -68°C., the plate and weld were heavily hammered and no cracks occurred.

Analysis:-

Phosphorus	0.030 %
Sulphur	0.034
Silicon	0.181
Manganese	0.692
Carbon	0.229
Copper	0.062
Chromium	0.739
Nickel	0.067
Molybdenum	0.255
Aluminium	0.014
Alumina	0.0090
Nitrogen	0.0065

McQuaid-Ehn
Grain Size:-

Steel B.

0.030 %
0.034
0.181
0.692
0.229
0.062
0.739
0.067
0.255
0.014
0.0090
0.0065

8 - 9 }
some 7

Steel A.

0.046

.040

.0911

.66

.271

.04

.078

TRACE

.006

Trace

.004

.006

Trace

.004

Trace

.004

Trace

.004

NOTE:

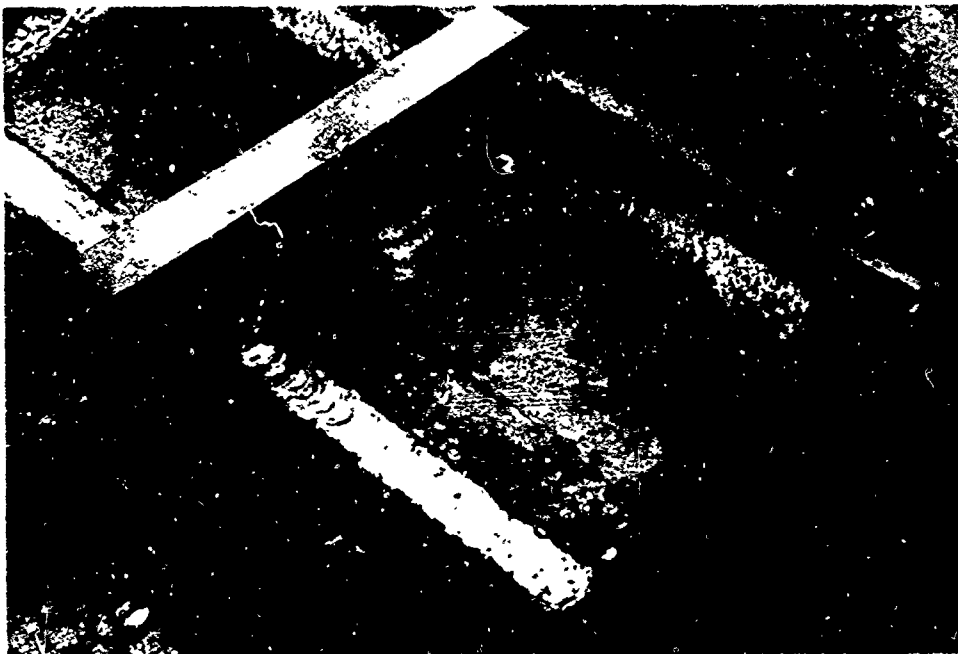
Steel A has higher
Transition Temperature than Steel B as
indicated by Notched Bar Impact Test.

FIG. 4

WELDING STANDARD PLATE MATERIAL IN HEAVY RESTRAINING FRAME.



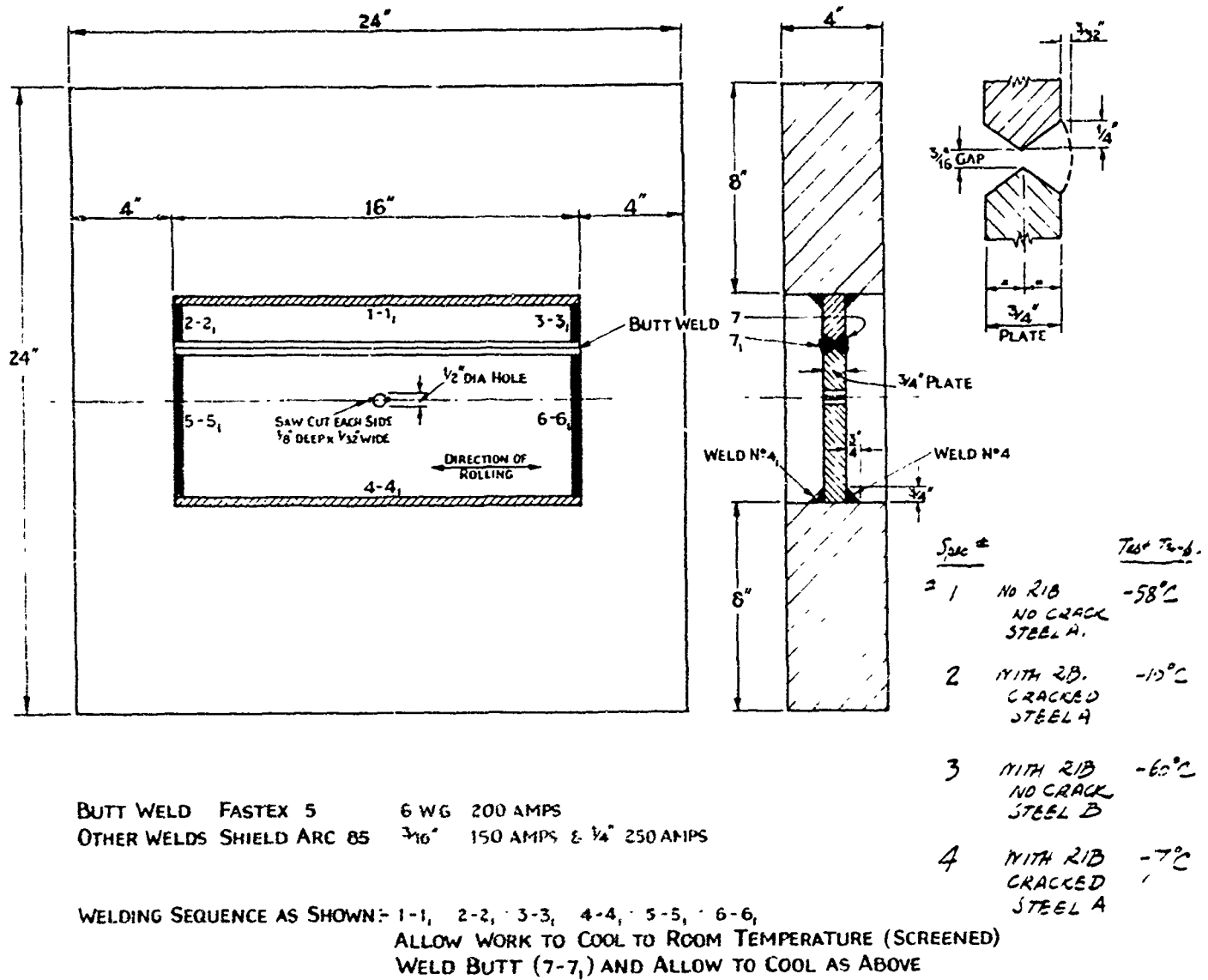
Same type test piece with heavy cross member showing crack commencing from slotted hole under cross piece.



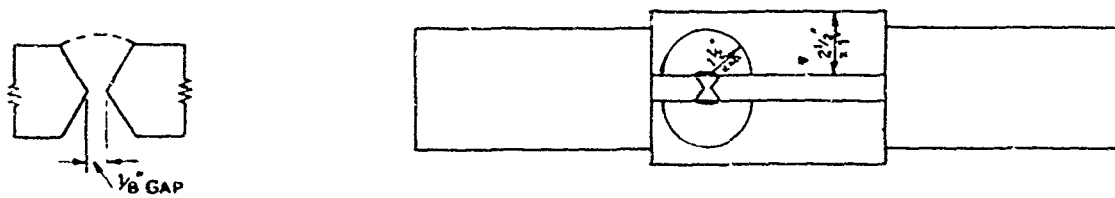
specimen
Same ~~view~~ as above showing appearance of crack at other side of plate.

Specimen # 2.
Steel A.

FIG. 5



DETAIL OF TEST PLATE FOR 1ST TEST.



DETAIL OF TEST PLATE FOR 2ND TEST
OTHER DETAILS AS FOR 1ST TEST ABOVE.

FIG. 6

F. MISCELLANEOUS

1. Corrosion - Professor U. R. Evans, Cambridge University, is interested in all aspects of corrosion studies, both theoretical as well as experimental. He has a number of students doing graduate work for their masters and doctors degrees.

Professor A. Preece at Kings College, Newcastle, is also interested in aspects of corrosion research. A paper entitled "Stress Corrosion Cracking of Mild Steel Structures," Transactions, Institution of Welding, December 1949, describes some of the work in this laboratory. This paper was prepared by C. E. Pierson and R. F. Parkins. In discussing this work with Mr. Parkins, he indicated that Bessemer steel may be more susceptible to stress corrosion cracking than open hearth steel.

2. Propeller Testing - A new closed propeller testing tunnel has just been built at Kings College, Newcastle. The tunnel is of the circulation type and will accommodate a propeller up to 24 inches in diameter. The maximum head at the centerline of the propeller is 35 feet and the pump is large enough to circulate water through the testthroat at 35 to 40 feet per second. The tunnel is undergoing "shake-down" at present. The Department of Naval Architecture which operates this tunnel is under the direction of Prof. L. C. Burrill.

Professor Burrill is interested in all aspects of propeller design and research, and is currently conducting an investigation for the British Shipbuilding Research Association on "Propeller Blade Vibration." The aim of this study is to secure possible explanations of corrosion and singing.

3. Other Studies at Kings College, Newcastle (under the direction of Prof. Burrill, Department of Naval Architecture). - A paper was recently

presented before the Northeast Coast Institute of Engineers and Shipbuilders on "The Application of Basic Functions to Girder Networks." A copy of this paper has been forwarded to Mr. John Vasta of the Bureau of Ships for comment. Another paper is in preparation entitled "Thermal Expansion Effects in Composite Ships." This paper will be presented at the Spring 1950 meeting of the Institution of Naval Architects. Both of the above papers have been prepared by Mr. E. C. B. Corlett. In discussing the the second paper with Mr. Corlett, he indicated that this report is an extension of the paper by O. Hurst entitled "Deflection of Girders and Ship Structures: A Note on Temperature Effects," Transactions, Institution of Naval Architects. Mr. Corlett promised to make preprints of his paper available to us for comment and discussion. This paper not only covers the theoretical aspects of the effect of non-linear temperature gradients, but also outlines some experimental work conducted by Mr. Corlett in verifying his theory.

4. Failures in Swedish Ships - Serious failures have occurred in several Swedish ships. Three such failures have been reported by Lloyds Registry to the Admiralty Shipwelding Committee in Report FE4/282, August 1949. A brief description of these failures follows. Details and photographs of the fracture will be found in the reports.

M.T. "FALSTERBOHUS"

Particulars in ship: Longitudinally framed tanker 480' x 66' x 37'3" moulded dimensions 10, 236 tons gross. Built by Kockums Mek, Malmo, Sweden in 1941. Mainly welded construction.

Circumstances of Casualty: Whilst on a voyage from Gothenburg to Malmo, partially loaded, in moderate weather, with air temperature 3°C and sea temperature 9°C, a mine is said to have exploded, and the ship

fractured suddenly in several places. The main fracture was in the vicinity of frame station No. 52, i.e., amidships (near a main oiltight bulkhead) and ran right across the deck and down both sides to the bilge. The two longitudinal bulkheads in way were also fractured. This main fracture was brittle in appearance, and had several branches. Another major fracture occurred near the oiltight bulkhead on frame 46, and extended from the starboard gunwale through $2\frac{1}{2}$ strakes of deck plating and downwards through three strakes of shell plating. The starboard longitudinal bulkhead, and the transverse bulkhead in way were also fractured.

M.S. "RAUNALA"

Particulars of Ship: Combined ore carrier and oil tanker, 458" x 59' x 35'6" approx. moulded dimensions, 9127 tons gross, built by Gotaverken, Gothenburg, Sweden, during the war, and completed in April 1946, partially welded. (Side shell seams riveted). Transversely framed.

Circumstances of Casualty: While the ship was lying at the builders' quay on 18.1.49 after completion of some repairs, tanks were pumped up for testing, when the ship suddenly cracked, and a number of major fractures appeared. Main crack from forward port corner No. 4 hatch, ran across the deck and down the side through two strakes. Second crack from forward starboard corner No. 3 hatch, 7'6" across deck, 7" up hatch coaming and 5'3" down the longitudinal bulkhead. Third crack from after starboard corner of No. 4 hatch, 6'0" across deck, 7" up the hatch coaming and 2' 0" down longitudinal bulkhead. There were also a number of minor fractures. The air temperature at the time was 0°C, and the sea temperature 2° to 3°C. The normal stress calculated at the position of the main fracture was about 4 tons/sq.in. The fractures were brittle in character, with chevron

markings pointing to the origins of the fractures at the hatch corners. The hatch corners are rounded, but the deck plate is slotted through the coaming (see Fig. A).

The steel for the ship was made in Germany during the war, and checked (tensile and bend tests) in Sweden. Particulars of manufacture are not known.

M.T. "TANKLAND"

Particulars of Ship: Transversely framed tanker of Deutsche Werft type, 465' x 60'9" x 34' moulded dimensions 8,361 tons gross, built by Eriksberg Medk, launched 1941, commissioned May 1945. Partly welded (shell seams riveted).

Circumstances of Casualty: The vessel has sustained a number of minor fractures from time to time, but the present report is concerned primarily with a fracture which occurred in August 1948, when bilge plate No. D.5. port cracked for practically the full width of the plate. The bilge keel bulb-plate is riveted to a flat bar which is welded to the bilge shell plating. The fracture appears to have originated either at one of the riveted holes in the flat bar, or in the weld attaching the flat bar to the shell. The fracture travelled upwards and downwards, the upper end being at the edge of the strake, where it passed between two pairs of rivets in the overlap. The lower end is in one of the rivet holes connecting the plating to a frame, just above the lower edge of the strake. The sea and air temperatures at the time of the fracture were in the vicinity of 15°C. The ship was at sea in moderate weather. An investigation of the loading conditions showed these to be unfavorable, giving a still water sagging stress of 4 t/sq.in. or about 10 t/sq.in. sagging on a standard wave. The steel was of German origin.

A similar fracture, in Plate D.7, starboard occurred in January 1949.

The occurrence of failures in Swedish ships will undoubtedly induce Swedish shipbuilding interests to conduct research work on the problem of brittle fracture in ships. The concern over such failures is manifested by KOCKUMS MEKANISKA VERKSTADS AKTIEBOLAG (builders of the "FALSTERBOHUS") by their purchase of notch tough high manganese normalized steel as discussed under the paragraph on Messrs. Colvilles, Ltd, of Section A of this report. In addition, I have received a letter recently from the Chief of the Metallurgical Laboratory of one of the Swedish Electrode manufacturers in which he states: "We are going on with quite a lot of research studies of brittle fracture in mild steels and working seriously on the problem. There is a very good collaboration among the Swedish steel works, electrode manufacturers, and shipyards under the leadership of Jernkontoret which, as you perhaps know, is a central institution in Sweden for metallurgical research work."

5. The Indexing and Analysis of Survey Reports.

Lloyds Register is keeping a continuing record of fractures in ships. These are recorded on cards for ready reference. The edges of the cards are notched to identify the cause, the location, the extent etc., of the crack. By inserting a pin through a particular notch on the edge of the cards when the cards are shaken those ship fractures of interest can easily be picked out. A description of this method of indexing is available. A sample card is attached hereto as Exhibit C.

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BALLAST												U.S.A.												U.S.A.												U.S.A.											
OTHER												U.S.A.												U.S.A.												U.S.A.											
E.A.B. SPACE												U.S.A.												U.S.A.												U.S.A.											
DE. ENCLOSURES												U.S.A.												U.S.A.												U.S.A.											
PAINTING AREA												U.S.A.												U.S.A.												U.S.A.											
SLAMMING												U.S.A.												U.S.A.												U.S.A.											
STRINGER PLATE												U.S.A.												U.S.A.												U.S.A.											
OTHER PLATING												U.S.A.												U.S.A.												U.S.A.											
BEAMS												U.S.A.												U.S.A.												U.S.A.											
TRANS												U.S.A.												U.S.A.												U.S.A.											
LONGLS												U.S.A.												U.S.A.												U.S.A.											
GIRDERS												U.S.A.												U.S.A.												U.S.A.											
OPENINGS												U.S.A.												U.S.A.												U.S.A.											
WEATHER DK												U.S.A.												U.S.A.												U.S.A.											
LOWER DXS												U.S.A.												U.S.A.												U.S.A.											
SUPER												U.S.A.												U.S.A.												U.S.A.											
KEEL GIRDER												U.S.A.												U.S.A.												U.S.A.											
KEEL												U.S.A.												U.S.A.												U.S.A.											
BOSSING												U.S.A.												U.S.A.												U.S.A.											
BILGE KEEL												U.S.A.												U.S.A.												U.S.A.											
BILGE												U.S.A.												U.S.A.												U.S.A.											
OUTBOARD												U.S.A.												U.S.A.												U.S.A.											
INBOARD												U.S.A.												U.S.A.												U.S.A.											
I.B. PLATE												U.S.A.												U.S.A.												U.S.A.											
D.B. STRUC.												U.S.A.												U.S.A.												U.S.A.											
T.V. PLATE												U.S.A.												U.S.A.												U.S.A.											
LONGLS												U.S.A.												U.S.A.												U.S.A.											
FLOORS												U.S.A.												U.S.A.												U.S.A.											
KEEL GIRDER												U.S.A.												U.S.A.												U.S.A.											
KEEL												U.S.A.												U.S.A.												U.S.A.											
SIDES												U.S.A.												U.S.A.												U.S.A.											
UPPER												U.S.A.												U.S.A.												U.S.A.											
LOWER												U.S.A.												U.S.A.												U.S.A.											
FRAMES												U.S.A.												U.S.A.												U.S.A.											
WEB FRAMES												U.S.A.												U.S.A.												U.S.A.											
LONGLS												U.S.A.												U.S.A.												U.S.A.											
GIRDERS												U.S.A.												U.S.A.												U.S.A.											
OPENINGS												U.S.A.												U.S.A.												U.S.A.											
BULWARKS, ETC.												U.S.A.												U.S.A.												U.S.A.											
SEAMS & BUTTS												U.S.A.												U.S.A.												U.S.A.											
CONNECTIONS												U.S.A.												U.S.A.												U.S.A.											
STUITS												U.S.A.												U.S.A.												U.S.A.											
PILARS												U.S.A.												U.S.A.												U.S.A.											
STANCHIONS												U.S.A.												U.S.A.												U.S.A.											
SEATINGS												U.S.A.												U.S.A.												U.S.A.											
EQUIPMENT												U.S.A.												U.S.A.												U.S.A.											
FITTINGS												U.S.A.												U.S.A.												U.S.A.											
RUDDER												U.S.A.												U.S.A.												U.S.A.											
STERN FRAME												U.S.A.												U.S.A.												U.S.A.											
LONG. BHDS.												U.S.A.												U.S.A.												U.S.A.											
T.V. STIFF												U.S.A.												U.S.A.												U.S.A.											
WEB STIFF												U.S.A.												U.S.A.												U.S.A.											
STRINGER												U.S.A.												U.S.A.												U.S.A.											
COOP												U.S.A.												U.S.A.												U.S.A.											
N.W.T.												U.S.A.												U.S.A.												U.S.A.											
ALTERATION												U.S.A.												U.S.A.												U.S.A.											
CORROSION												U.S.A.												U.S.A.												U.S.A.											
LOST GEAR												U.S.A.												U.S.A.												U.S.A.											
RIV												U.S.A.												U.S.A.												U.S.A.											
E.W.												U.S.A.												U.S.A.												U.S.A.											
DEFORM												U.S.A.												U.S.A.												U.S.A.											
FRACTURE												U.S.A.												U.S.A.												U.S.A.											
BALLAST												U.S.A.												U.S.A.												U.S.A.											
LIQUID												U.S.A.												U.S.A.												U.S.A.											
BULK												U.S.A.												U.S.A.												U.S.A.											
GRAIN												U.S.A.												U.S.A.												U.S.A.											
GEN.												U.S.A.												U.S.A.												U.S.A.											
MAJOR												U.S.A.												U.S.A.												U.S.A.											
OTHERS												U.S.A.												U.S.A.												U.S.A.											
SHIFT												U.S.A.												U.S.A.												U.S.A.											
VIB.												U.S.A.												U.S.A.												U.S.A.											
W. & F.												U.S.A.												U.S.A.												U.S.A.											
H.W.												U.S.A.												U.S.A.												U.S.A.											
COLLISION												U.S.A.												U.S.A.												U.S.A.											
WAR. FINE												U.S.A.												U.S.A.												U.S.A.											
ALLOY												U.S.A.												U.S.A.												U.S.A.											
SPEC.												U.S.A.												U.S.A.												U.S.A.											
LONG.												U.S.A.												U.S.A.												U.S.A.											
MIX.												U.S.A.												U.S.A.												U.S.A.											
TRANS.												U.S.A.												U.S.A.												U.S.A.											
RIV												U.S.A.												U.S.A.												U.S.A.											
MIX												U.S.A.												U.S.A.												U.S.A.											
EW.												U.S.A.												U.S.A.												U.S.A.											

Exhibit C.

PAT. NOS. 228088 287882, 48 C.C. 181818

SCHNADT TEST

A Summary* of Discussion with M. Henri Schnadt and of his
Lecture at the Institute of Welding, London, Nov. 30, 1949.

The von Mises - Huber - Hencky expression for the generalized
shear stress "k" is defined by the quadratic stress invariant, thus

$$k = f \left(\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \right)$$

"k" can be related to the yield stress in simple tension and therefore
for a given material $k = \text{const.}$

If the above radical is expanded and divided by σ_1 (principal
stress) then

$$\frac{k}{\sigma_1} = \frac{\text{const.}}{\sigma_1} = \psi \left(\sqrt{1 + \eta_2^2 + \eta_3^2 - \eta_2 \eta_3 - \eta_2 - \eta_3} \right)$$

* This summary is based on my own notes and on a resume which Dr. R. Weck, B.W.R.A., has very kindly made available to me. This resume (in draft form) is being prepared to summarize Schnadt's London lecture.

when

$$\eta_2 = \frac{\sigma_2}{\sigma_1} \quad \text{and} \quad \eta_3 = \frac{\sigma_3}{\sigma_1}$$

M. Schnadt has called the dimensionless expression

$$\pi = \sqrt{1 + \eta_2^2 + \eta_3^2 - \eta_2 - \eta_3 - \eta_2 \eta_3}$$

the "Plastifying Power" - thus

$$\pi \sigma_1 = \text{const.} \quad (1)$$

M. Schnadt claims all stresses of practical engineering importance are included between these limits:

a) $\eta_3 = 0$ and $\eta_2 = 0.5$ (Dinacic Stresses) (2)

b) $\eta_3 = 0.5$ and $\eta_2 = 0.75$ (Coheracic Stresses) (3)

He believes these stresses can be realized in small test pieces by virtue of their large width to thickness ratio (3.3) and because of the notches used.

Thus Dinacic and Coheracic stresses are present in the bars shown in

Fig. 7 where the root radius "d" equals ∞ and 0 respectively.

For Dinacic Stresses $\pi = 0.866$

Coheracic Stresses $\pi = 0.433$

Thus the lower the value of the plastifying power the higher the transition temperature of the specimen or structure.

A continuous change in the plastifying power π is achieved by varying the root diameter "d" of the notch. See Fig. 8. Since only the dinacic and coheracic specimens can be discussed in terms of the state of stress in the specimen, M. Schnadt has proposed that the difference, between $\pi = 0.866$ and $\pi = 0.433$, be divided into 100 units or Venants as follows:

$$Ve = \text{Venants} = 100 \frac{d}{d + 2}$$

Thus

Dinacic Stresses	(d = ∞)	Ve = 100)
Mesatopic Stresses	(d = 2)	Ve = 50)
Ponatopic Stresses	(d = 1)	Ve = 33.3)
Ganatopic Stresses	(d = 0.5)	Ve = 20.)
Coheracic Stresses	(d = 0.0)	Ve = 0 (See Fig. 8 for details of notch))

See
Fig.
7

Based on the above, M. Schnadt says all practical states of stress are given by plastifying powers between 0 and 100 Ve.

The energy absorbing ability (K_d) of a steel will vary as $f(\pi)$ (expressed in Venants) at constant temperature as shown in Fig. 9.

The test bars are broken in the impact machine as shown in Fig. 10.

Based presumably on experience, M. Schnadt states that

$K_d = 2 \text{ Kgm/cm}^2$ indicates low plasticity (brittle)

$K_d = 5 \text{ Kgm/cm}^2$ indicates mean plasticity

$K_d = 8 \text{ Kgm/cm}^2$ indicates full plasticity (ductile)

If now the curves shown in Fig. 9 include the lowest operating temperature of the structure, M. Schnadt claims (again presumably based on experience) that some plastic flow will precede fracture when

$K_d = 2$ (at lowest operating temp.)

$\pi > 17$ Venants

Further, if the structure is to behave in a fully plastic manner, then its plastifying power π (in Venants) must exceed that corresponding to $K_d = 8$ at the lowest service temperature.

SUMMARY

1. Five specimens are usually used, as follows:

d = ∞	dinacic)	
)	
d = 2 mm	mesatopic)	
)	See Figs. 7 and 8
d = 1	ponatopic)	
)	
d = 0.5	ganatopic)	
)	
d = 0	coheracic)	

2. Specimens tested in impact machine
3. Compression zone removed - hardened pin inserted. See Figs. 7 and 10
4. Tested at service temperatures of structure and other temperatures.
5. Scatter is claimed not to occur in "homogeneous" materials

6. The test has been applied to prestrained (and aged) material as shown in Fig. 11.
7. The test may also be used for determining the suitability of electrodes by studying the deposited weld metal and the heat affected zone as shown in Fig. 12.

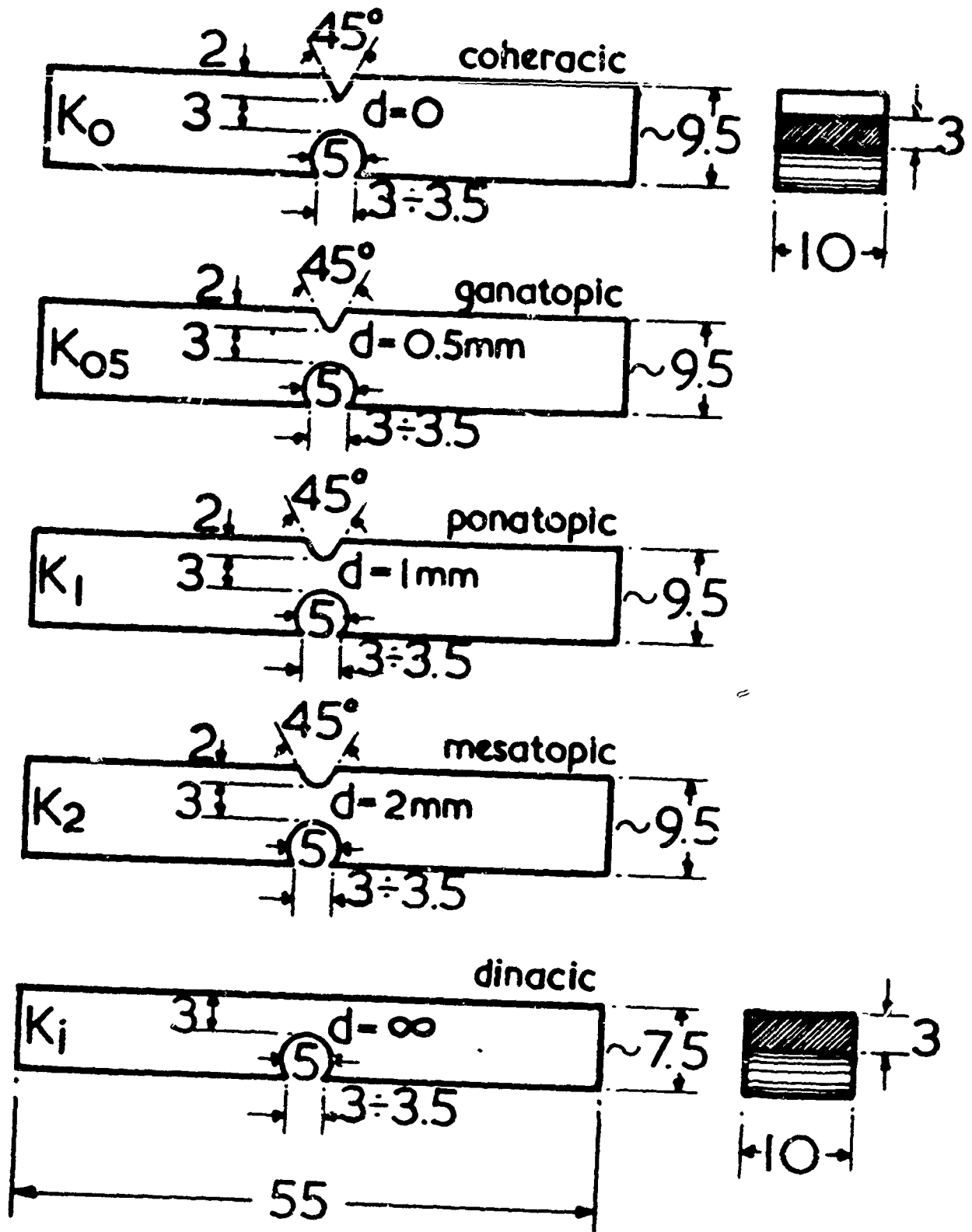


Figure 7

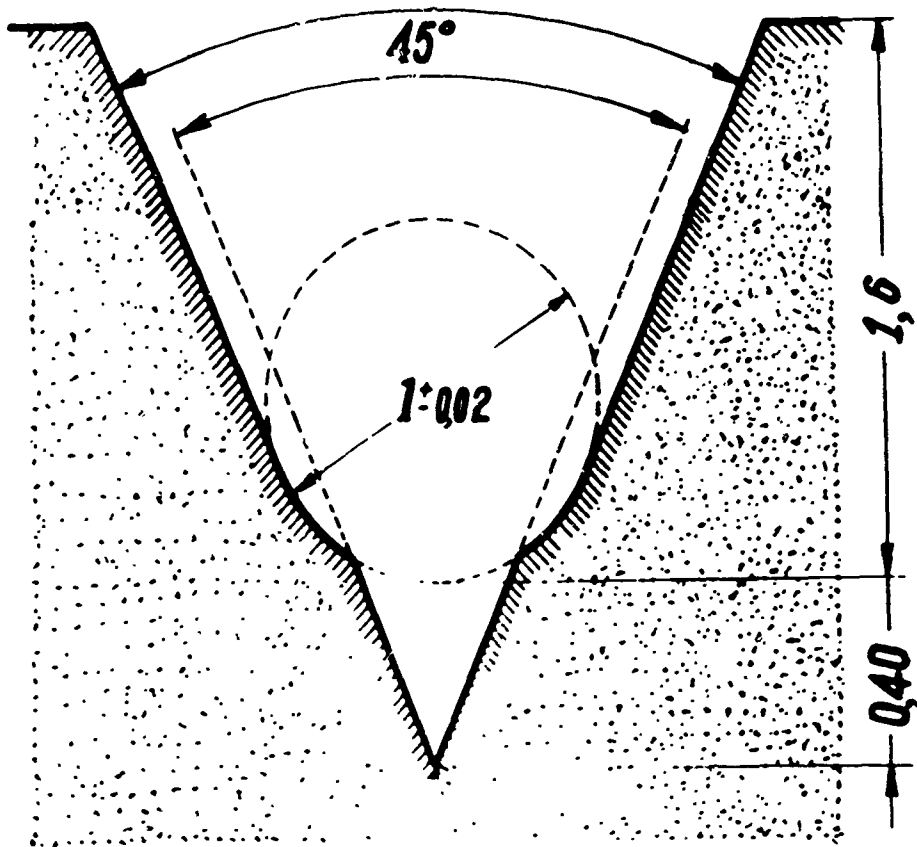


Figure 8

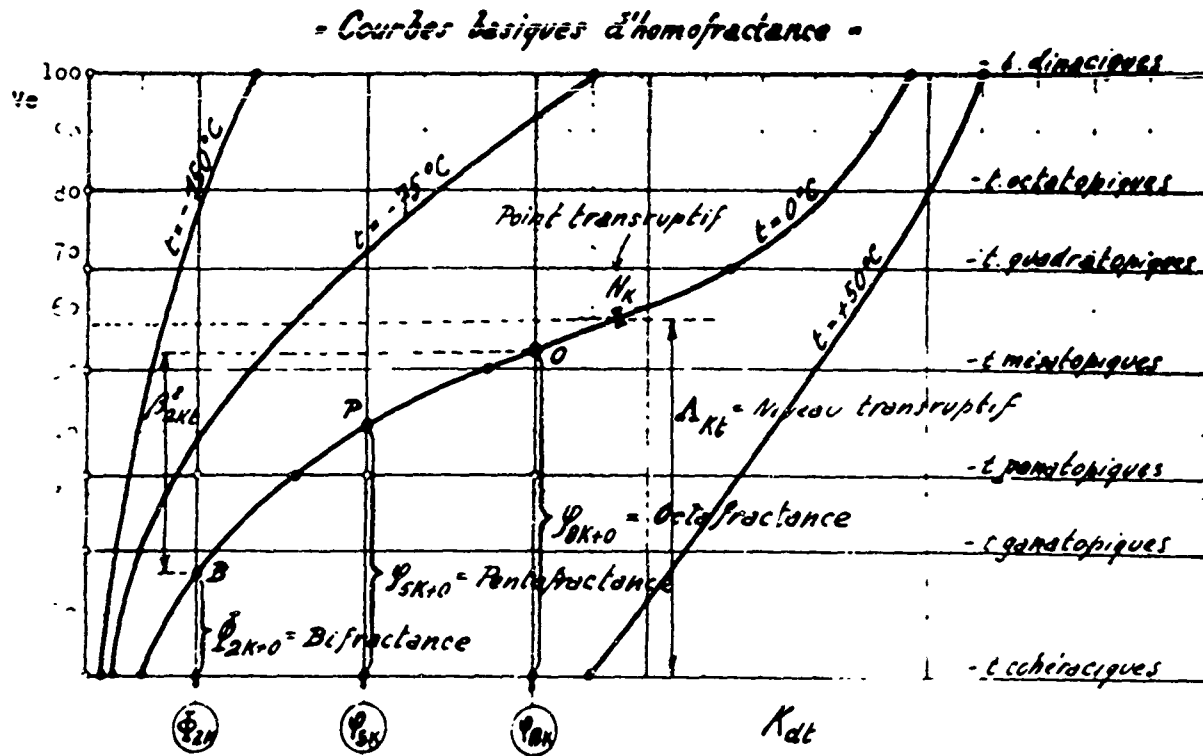


Figure 9

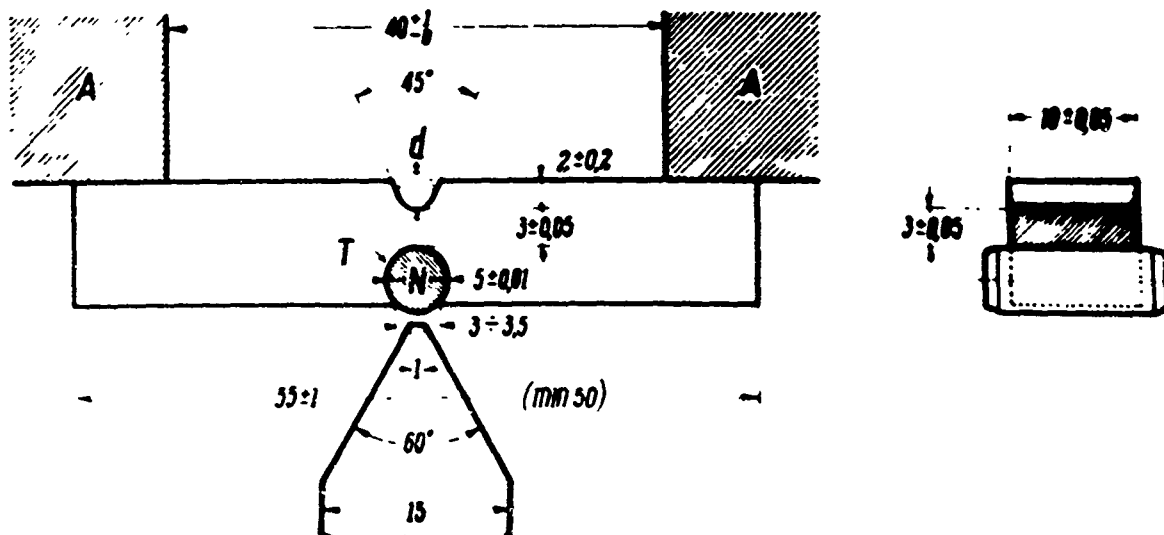


Figure 10

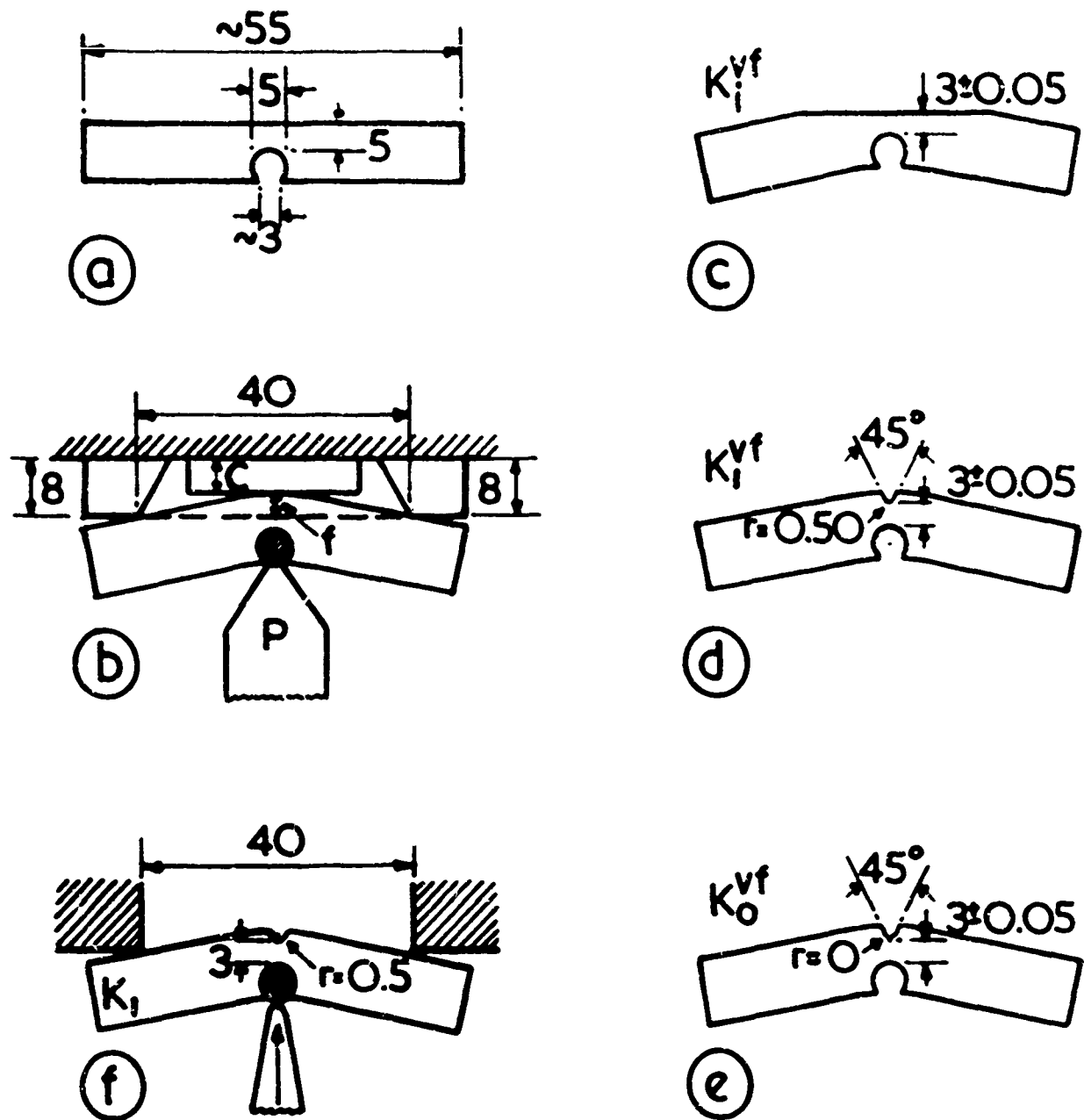


Figure 11

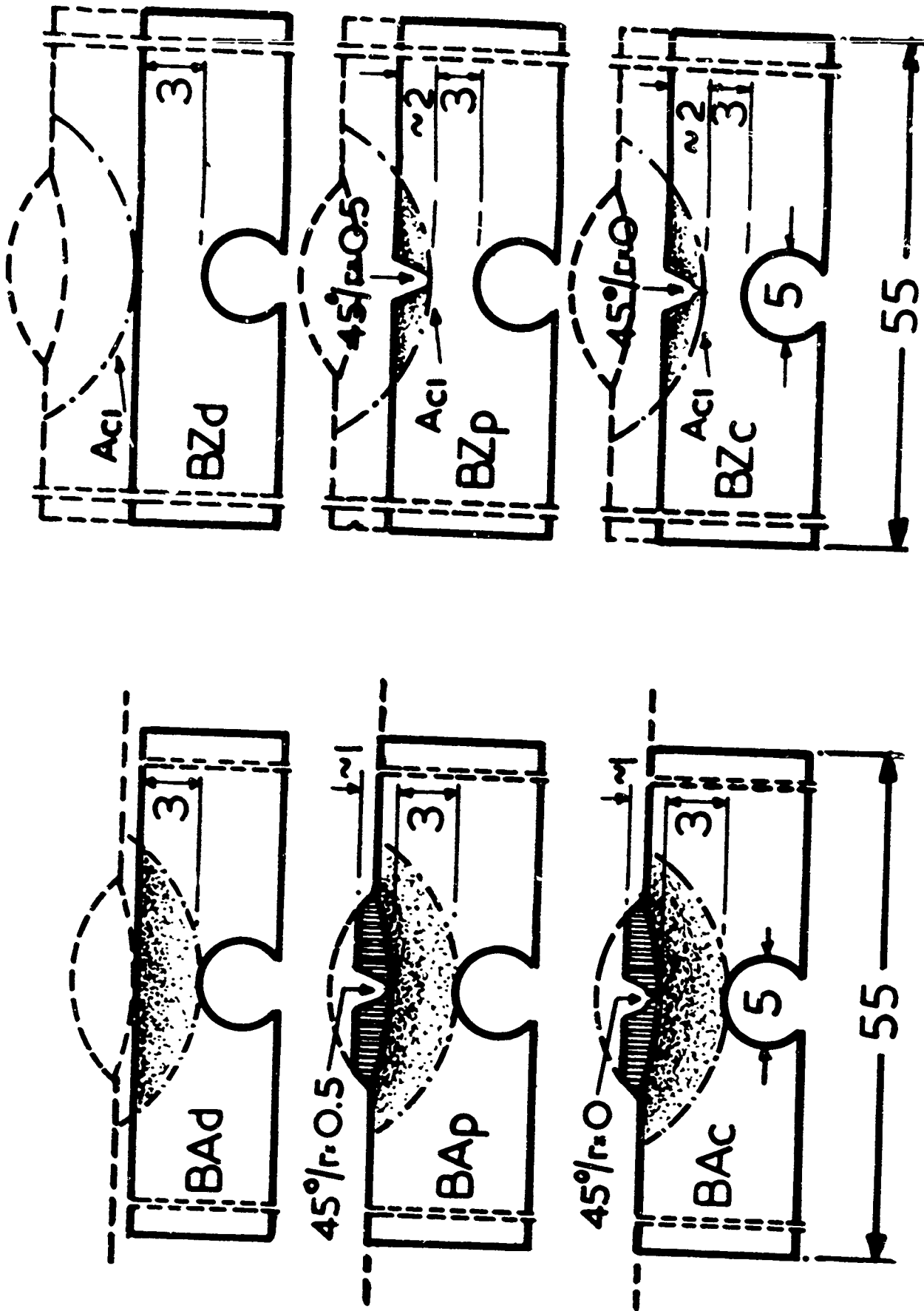


Figure 12

ITINERARY

Oct. 28	Called on U. S. Naval Attache	R. Adm. Cornwell Capt. Cole Capt. Clay
Oct. 29 & 30	Free	
Oct. 31 AM	Called on DRPP and DAER - Admiralty	Mr. Thornycroft Mr. Cross
Oct. 31 PM	Called on Chairman British S/B Conference	Sr. Amos Ayre
Nov. 1 AM	Called on DNC - Admiralty	Sir Chas. Lilliecrap
Nov. 1 PM	Called on International Inst. of Welding	Mr. Parsloe
2 AM	Called on BSRA	Dr. S. L. Smith
PM	Called on CE Dept. U. of London	Prof. Pipnard
3 AM	Called on Lloyds Registry	Mr. Shephard
PM	Called on BISRA	Dr. Becker
4	Called on NPL - Teddington	Mr. Dennison Mr. Rees Mr. Hopkins
	Eve. met Dr. N. P. Allen, Supt. Metl. Res. NPL	
5	Free	
6 PM	Travel to Cambridge	
7 - 11	Cambridge Univ. - Saw Prof. Baker & Associates, Prof. Orowan, Prof. Austin, Prof. Evans, BWRA, Dr. Taylor, Dr. Weck	
12	Free	
13	Travel to London and to Edinburg	
14	Burntisland S/B Co.	Mr. Douthwaite
15	NCRE - Rosyth	Mr. Offord & Associates
16	Travel to Newcastle	
17	Visited S/B Yards of Vickers - Armstrong and Swan Hunter & Wigham Richardson at Newcastle-upon-Tyne.	Mr. George Holden Mr. N. M. Hunter
18	Visited Kings College, Newcastle	Prof. Burrill & Preece
19	Free	
20	Travel to Birmingham	
21	Visited Univ. of Birmingham	Prof. D. Hansen Prof. Cottrell Dr. Raynor
21	Visited Mond Nickel Co. - Research Lab. (Birmingham)	Mr. Hignett

Nov. 22	Travel to London	
23 AM	Luncheon with Sir Amos Ayre and Capt. Cole	
PM	Attended Meeting A.S.W. Committee in London	
24	DDNC - Bath	Mr. Shephard Mr. Bartlett Capt. Pengelly
25	Bristol Univ.	Prof. Pugsley Dr. Price
26	Free	
27	Travel to London and then Glasgow by sleeper	
28	Colvilles, Ltd. Glasgow	Sir Andrew McCance Mr. W. Barr and Associates
29	Visited the Clyde Shipyards of John Brown Co., Ltd. and Harland and Wolff with Sir Amos Ayre	Mr. Rannie Mr. Dunlap
	Eve. returned to London	
30 AM	Met Dr. Schnadt at BWRA Eve. attended meeting of Inst. of Welding	
Dec. 1 AM	Called on BSRA	Dr. Conn
PM	Called at NPL	Mr. Rees Mr. Hopkins
2	Called at Stewarts & Lloyds at Corby - Kettering	
3	Free	
4	Free	
5	Called on CML at Emsworth (Havant)	Dr. Burns Mr. Kenworthy
6 AM	Called on BWRA - London	Dr. Taylor
PM	Met with Dr. Tipper, Mr. Boyd and Mr. Grainger for resume.	
7 AM	Left for Sheffield	
PM	Univ. of Sheffield	Prof. Andrew
8 AM	Univ. of Sheffield	
PM	Returned to London	Prof. Swift
9 AM	Called on L.R. for resume	Mr. Shephard & Assoc.
PM	Luncheon with Sir Chas. Lillcrap and Capt. Cole	
10 AM	Left for Southampton to return to USA	